THE GEOLOGY OF THE EL TIRO MINE

Silverbell, Arizona

By

A.H. Shoemaker and Geo. Somers

This thesis is submitted to the Graduate Study Committee and Department of Geology and Mineralogy as partial fulfillment of the requirements for the degrees of Master of Science and Mining Geologist.

A. H. Shoemaker
Candidate for Master of Science

Geo. Somers
Candidate for Mining Geologist
INDEX

<table>
<thead>
<tr>
<th>Introduction</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>1</td>
</tr>
<tr>
<td>History</td>
<td>2</td>
</tr>
<tr>
<td>Methods of Field Work</td>
<td>3</td>
</tr>
<tr>
<td>Topography</td>
<td>5</td>
</tr>
<tr>
<td>General Description of Rocks of District</td>
<td>6</td>
</tr>
<tr>
<td>Sedimentary Rocks</td>
<td>8</td>
</tr>
<tr>
<td>Silverbell Quartzite</td>
<td>8</td>
</tr>
<tr>
<td>Altered Limestone</td>
<td>9</td>
</tr>
<tr>
<td>Age and Correlation of Sedimentaries</td>
<td>10</td>
</tr>
<tr>
<td>Recent Conglomerate</td>
<td>12</td>
</tr>
<tr>
<td>Igneous Rocks</td>
<td>12</td>
</tr>
<tr>
<td>General Statement</td>
<td>12</td>
</tr>
<tr>
<td>Granites</td>
<td>12</td>
</tr>
<tr>
<td>Mt. Hope Granite</td>
<td>13</td>
</tr>
<tr>
<td>Biotite Granite</td>
<td>14</td>
</tr>
<tr>
<td>Granite Porphyry</td>
<td>16</td>
</tr>
<tr>
<td>Pyroxene Porphyrite</td>
<td>17</td>
</tr>
<tr>
<td>Granite Porphyry Dike</td>
<td>18</td>
</tr>
<tr>
<td>Syenite Porphyry</td>
<td>18</td>
</tr>
<tr>
<td>Age Relations of Intrusives</td>
<td>19</td>
</tr>
<tr>
<td>Faulting and Fracturing</td>
<td>20</td>
</tr>
<tr>
<td>Economic Geology</td>
<td>21</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>21</td>
</tr>
<tr>
<td>Development and Methods of Mining</td>
<td>29</td>
</tr>
<tr>
<td>Types of Deposits</td>
<td>31</td>
</tr>
<tr>
<td>Disseminated Deposits</td>
<td>32</td>
</tr>
<tr>
<td>Primary Ore</td>
<td>32</td>
</tr>
<tr>
<td>Structural Features Determining</td>
<td></td>
</tr>
<tr>
<td>Position of Ore Bodies</td>
<td>33</td>
</tr>
<tr>
<td>Enrichment of the Ore</td>
<td>35</td>
</tr>
<tr>
<td>Origin of the Ore</td>
<td>37</td>
</tr>
<tr>
<td>Types of Alteration and Nature of</td>
<td></td>
</tr>
<tr>
<td>Ore-Bearing Solutions</td>
<td>38</td>
</tr>
</tbody>
</table>

51376
INTRODUCTION.

The mining camp of Silverbell has for many years ceased to be an important producer of copper. Because of this fact the literature on the district is very meager. Only one paper dealing in any detail with the geology has been written. Other short extracts have been written for the mining magazines, but they are too general to be of much value.

The writers have undertaken the study of the El Tiro property in detail. Although general interest in Silverbell is lacking at present, the material presented here should


have some value, since it defines the geologic relationship of the district to others of this southwest region, and adds one more example to the list of copper deposits associated with acidic or monzonitic intrusions.

The field work upon which this thesis is based, was done in the fall of 1923, and was made possible by the courtesy of the El Tiro Leasing Company, which gave us access to its property. The writers wish to express their thanks for this kindness and courtesy to Robert E. Anderson, the superintendent, who placed maps, the guest house, and mine at our disposal, and also discussed with us the problems of the mine, and district as a whole.

The report by Mr. C.A. Stewart has been drawn upon to some extent, in considering the general geology of the district.

The writers wish particularly to express their thanks to Mr. Carl Lausen of the Arizona Bureau of Mines for his many helpful suggestions, and interest in this work.

LOCATION

The El Tiro Mine is situated in the Silverbell Mining District in Pima County, Arizona. This district lies about 40 miles west of Tucson and 20 miles south of Red Rock, both of which are on the main line of the Southern Pacific Railroad. It is connected with the Southern Pacific at Red
Rock by the Arizona Southern Railroad, a standard gauge line built and still operated by the Imperial Copper Company. It can also be reached by auto, either direct, or via Red Rock, the latter route being better but somewhat longer.

The Silverbell Mountains, in which the district lies and from which it received its name, are the northern spur of a low, rugged mountain range known as the Roskruge. This range, like similar ones in the vicinity, rises sharply from the flat desert.

The district is somewhat low, its elevation varying from 2500 to 4000 feet. This elevation makes its climate, though dry and hot, considerably cooler than that of Red Rock and Tucson, which lie in the middle of flat "semi-bolsons." The vegetation, though changing noticeably with elevation, is typical of desert regions and consists of mesquite, various cacti, and other forms. The elevation is not sufficiently great to get into the Manzanita, or live oak zone.

**HISTORY**

The district was first worked about 1865. The heavy, black, copper stained garnet outcrops have attracted numerous prospectors since then, but though several rich pockets of lead-silver ore were opened up, the real development of the copper deposits did not begin until 1903, when the Mammoth
(formerly Old Boot) and Union Mines were worked by the Imperial Copper Company. In 1904 this company built the Arizona Southern Railway to connect Silverbell with Red Rock. That same year the production reached three million pounds of copper, which amount was increased yearly until 1909, at which time the total annual production reached eleven million pounds.

For the first few years all of the ore mined was shipped to the Copper Queen works at Douglas, Arizona, for reduction, but in 1908 the Imperial Copper Company built a smelter of 800 tons capacity at Sasco, a small town on the Arizona Southern Railway between Silverbell and Red Rock. Here the ore was smelted until August of 1910, when owing to the depression and uncertainty of the copper industry, the mines were closed. Development was carried on for some time in both the contact and disseminated deposits, churn drills being used to explore the latter type.

The date of discovery of the El Tiro group of claims was unknown by any of the men working at the mine. The present company, the El Tiro Leasing Company, was formed to operate this property in 1919. This company mined and shipped ore intermittently until August 1923, at which time the Calumet and Arizona Mining Company took over the lease. In February of 1924, the El Tiro Leasing Company again took control of the property.

East of the district are a number of small lead-silver fissure veins which have been filed on, and worked by residents
of Silverbell. The largest prospect of this class is the Stump Mine, which is situated three or four miles from Silverbell on the road to Red Rock. From the dump, this deposit appeared to be a vein of quartz, calcite, galena, and sphalerite in pre-Cambrian granite. An inclined shaft has been sunk to a depth of one hundred feet and a drift run from there to prospect the vein.

**METHODS OF FIELD WORK.**

Both the surface and the underground workings were mapped. The first work done was to make a rough topographic map, and locate the geologic features. A geologic map made for the Imperial Copper Company was available which was found to be very accurate as to contacts. Elevations were determined by means of a Brunton Pocket Transit, using the known location of the Daisy shaft and location and elevation of the Kurtz shaft as a base. The topography is, therefore, only an approximation.

The geology of the mine workings was mapped in detail on the mine maps furnished by Mr. Anderson.

Some time was spent going over the whole district, mainly with the hope of finding definite data for the correlation of the sedimentary series.

In the laboratory thin sections of the rocks, and polished specimens of the ore were made to aid in accurate determination.
MAP OF THE SURFACE FEATURES OF THE
EL TIRO MINE
SILVER BELL - ARIZONA

SCALE 1" = 400' CONTOUR INTERVAL 25'
SOMERS & SHOEMAKER FEB. 1, 1924.

~LEGEND~
- BROWN - MT. HOPE GRANITE
- BLUE - GRANITE PORPHYRY
- GREEN - ALTERED LIMESTONE
- YELLOW - Biotite Granite
- RED - QUARTZITE
TOPOGRAPHY

Although changes in elevation are not great, the topography of the district is rugged.

In a general way the mountains of the desert region of Arizona have been compared to the Basin ranges of Gilbert, which represent lines of monoclinal or more rarely anticlinal folding.

The limitation of time makes it necessary to leave this an open question. Since in the area examined only a few remnants of sedimentary rocks engulfed in a series of intrusives were seen, it is just as probable that the whole Roskruge range is merely the remnant of a series of resistant igneous rocks, as that it belongs to the type described by Gilbert.

The streams are all intermittent. The permanent water level rises a few feet above the 300 station of the Kurtz. This brings the level within 175 feet of the surface in the creek bottom just south of the Daisy shaft.

GENERAL DESCRIPTION OF ROCKS OF DISTRICT.

This district as a whole consists of a series of Paleozoic sediments invaded by several large acidic and minor basic intrusives.
On the outskirts of the range to the north and east the pre-Cambrian granite is exposed. This is a very coarse, porphyritic granite with large quartz grains, flakes of biotite, and exceptionally large phenocrysts of pink orthoclase. It makes a most striking and easily identified rock.

South and east of the main body of sedimentaries is a large intrusion, called by Mr. Stewart, quartz porphyry. It consists of phenocrysts of quartz and orthoclase together with some biotite and plagioclase feldspar imbedded in a dense black groundmass. Perhaps "rhyolite porphyry" would be a more accurate term to apply to this rock.

It shows none of the characteristic alteration of the igneous rocks associated with the ore deposits. It intrudes the sedimentaries on their southern boundary. Its lack of mineralization and characteristic alteration causes it to be described as later than the intrusives connected with ore deposition.

South of the Silverbell Mountains lies the Roskruge range, made up of Tertiary volcanic flows. No visit was made to them, but they have been mapped by Messrs. Jenkins and Wilson of the Arizona Bureau of Mines, as Tertiary flows.

Surrounding the whole mountain mass is the typical valley fill of the southwest desert.

A detailed description of the rocks of the El Tiro property will be given.
SEDIMENTARY ROCKS

Silverbell Quartzite. A local name has been assigned by the writers to this formation, because of the lack of evidence definite enough to correlate it with any other district.

The largest outcrop occurs just to the east of the town of Silverbell. Two smaller exposures cap the hills directly west of the town. Throughout the area it occurs in small isolated outcrops. It is very resistant to erosion, the largest outcrop forming a very prominent ridge, while other outcrops cap high hills.

The characteristic color is a deep brownish red. However, on the western side of the town it is more of a buff color, while some of the smaller outcrops are almost white.

In thin sections it is seen to be composed of quartz grains of uniform size. Some isotropic foreign material is present, the composition of which was not determinable microscopically.

No thickness can be assigned to this formation. Probably it runs into the hundreds of feet, but the structure of the whole sedimentary series is so obscured by the action of the intrusives that an accurate determination is impossible.

From the relations shown on the geologic map, it must underlie the limestones.

A discussion of age relations and correlation can best be made in connection with a consideration of the same problem for the other sedimentaries.
Altered Limestone. These highly altered sediments occupy a large area approximately in the center of the district. A smaller outcrop occurs just a few hundred feet north-west of the Kurtz shaft. Still further to the north are several small and one large outcrop of an even more highly altered rock, differing somewhat in appearance, but having essentially the same mineral composition. No clear cut differentiation between these two types is justifiable. The reasons for this will be given after a more complete description.

From a distance, all of the outcrops of this limestone have a typical black, "burned", appearance. They are easily the most noticeable feature of the whole area.

A large proportion of the rock has been recrystallized into marble or altered to massive garnet. Some few small areas have the bluish gray appearance of an unaltered limestone. Locally the whole mass has been changed to wollastonite. Throughout the least altered portion, small crystals of wollastonite and veinlets of calcite can be seen.

The more highly altered rock differs from the commoner type in that the metamorphism has been more intense. Epidote and specularite have been more abundantly developed. Less marble and more massive garnet is the rule.

Cherty bands are common throughout the whole mass, with the exception of the massive garnet rock. These chert bands are remarkably regular in some parts of the rock and help to give a clue, on lithologic grounds, to a probable correlation of one horizon.
Only southeast of the Imperial Copper Company's holdings was there any reliable trace of the dip of the beds. There they were apparently dipping southeast from 45° to 90°. The alignment of the cherty bands suggested a possible method of determining strike and dip, but their direction was too variable to be of any assistance.

The original composition of these limestones probably did not vary greatly. Without the aid of a number of complete analyses no really definite information can be given. However, there is not enough variation in the mineralogical composition to justify as complete a separation as has been made by Mr. Stewart, i.e. calling the more highly altered sediments hornfels. The alteration is not at all like that commonly met with in shales. The presence of alumina as shown by the development of epidote, can easily be explained by assuming the presence of a few shaly bands. Had their composition been so widely different as that of a fairly pure limestone and an ordinary shale, some greater difference other than that of the development of a minor amount of epidote should be apparent.

Age and Correlation of Sedimentaries. Fossils were found in one horizon southeast of the Imperial Copper Company's property. Two forms that could be identified were collected, Menophyllum and Syringopera, both Mississippian. Mr. Lausen reports the finding of a Productus from the same locality. These three forms then represent the whole of the positive data for the correlation of the series.
On the basis of analogy, however, with the known sections of the neighboring mountains, more than carboniferous is undoubtedly present.

The regular-banded, cherty portions bear a marked resemblance to known Cambrian horizons. The Abrigo limestone of the Biabbee Quadrangle has much the same appearance, save that the metamorphism here has changed the limestone bands to marble. In the Caleria Hills, just west of the Tucson Mountains a Cambrian horizon very similar to that of Silverbell is represented.

Certainly this similarity does not give sufficient grounds for a definite correlation but it is very suggestive.

The quartzite, which underlies the limestone, then may or may not belong in the Cambrian. Lithologically it is very much like the Bolsa quartzite of Bisbee, but the description also fits the Troy or Dripping Springs quartzites of the Globe area. The probability is that it represents one of these three formations.

One of the puzzles of the stratigraphy of Southern Arizona is the relation between the basal Paleozoic of the Globe region and that of the Bisbee Quadrangle. Presumably the two should merge somewhere in the area between. No such mergence has as yet been observed.

In the Caleria Hills there is a section very similar to that of Bisbee; there are differences, but a discussion of them at this point is irrelevant. West and north of the Silverbell
Mountains in the Slate Mountains is a section of the Globe type\(^1\). Silverbell lies roughly half way between these two ranges. The fact that Silverbell is situated not far from an area of Globe type means nothing, for on the other side is an area with a Bisbee section.

The unfortunate fact of almost totally obscured structure makes it necessary then to leave the problem unsettled. All that can be said is that here is a thick quartzite and altered limestones - the limestones in part Mississippian, the quartzite and basal portion of the limestone probably Cambrian.

Recent Conglomerate. Across the mouths of many of the small gullies the detritus from the higher slopes has been firmly cemented with "caliche". In one place this conglomerate measured over eight feet in thickness.

**IGNEOUS ROCKS**

**General Statement.** The igneous rocks of the particular area under discussion are intrusives and with the exception of a few small dikes, acidic in character.

**Granites.** Two distinct granites can be recognized. In order to distinguish readily between the two, a local name has been assigned to one; the other has been given a minerallogically descriptive name.

---

\(^1\) Oral Communication from Mr. Lausen.
Mt. Hope Granite. Begins just west of the Kurtz shaft of the El Tiro mine and extends in that direction to the debris filled valley beyond. The trend of the eastern contact is generally northwest-southeast. It is more resistant to erosion than the other intrusions and forms the higher peaks of the western part of the Silverbell Mountains.

The rock is of a reddish-pink color and is composed of uniformly coarse grains of quartz and pink orthoclase, with either biotite or hornblende. Biotite is by far the commoner. Both the color and coarseness are distinctive features, which make this rock distinguishable from others even at a considerable distance.

At first glance, it appears to be made up entirely of quartz and orthoclase, but closer inspection reveals the presence or at least traces of the presence of a ferro-magnesian mineral. On the surface the biotite has often altered to a grayish-green substance, somewhat easy to mistake for kaolin.

The ferro-magnesian minerals are not evenly distributed through the mass. One area may be wholly lacking in biotite and ten feet away another may contain it in abundance.

This rock was named Alaskite by Prof. Tolman and has been so designated by subsequent geological investigators. That term, however, appears to the writers to be unsatisfactory. The meaning of the term, where first applied, was perhaps satisfactory, but its too general use later has made it vague. The writers prefer to call the rock an acid granite.
In thin sections this granite is seen to be composed of corroded quartz and sericitized and kaolinized orthoclase. A very minor percentage of the feldspar is plagioclase. In all of the sections examined the sericitization and kaolinization had progressed too far to permit the determination of the plagioclase. Mr. Stewart reports that it is almost pure albite.

Underground the texture remains the same, but everywhere the color is a light gray.

Developed along an east-west set of fractures, which traverses all the rocks of the district are fine grained, dike-like masses of aplite. These masses are not persistent along their strike. They vary greatly in thickness from a few inches to four or five feet. They are light brown or buff in color, and consist wholly of quartz and orthoclase. Evidently they represent the last phase before the solidifying of the acid magma.

Biotite Granite. The largest outcrops of this rock occur off the El Tiro property, one just west of the main outcrop of the Silverbell quartzite and another west of the largest body of limestone, in the vicinity of the Union tunnel. It is also exposed in the cut on the railroad at the eastern entrance to the surface tunnel connecting the Kurtz shaft with the loading platforms.

Sharp contacts of this rock with the granite porphyry could not be found. Within a short distance it is easy to tell that the transition from one to the other has been made, but the exact boundary escapes location.
Everywhere this rock is badly weathered. It has a brownish-yellow appearance due to limonitic stains. It consists of quartz and orthoclase and abundant biotite. The microscope reveals the presence of considerable plagioclase, usually near oligoclase in composition. There is less quartz than in the Mt. Hope granite. The percentage of orthoclase is greater than that of plagioclase. One exception to this was noted. A specimen taken at a contact of this granite and limestone showed nearly all plagioclase and the ferro-magnesian mineral was hornblende.

This granite lies wholly within the boundaries of the granite porphyry. In mineralogical composition it is very similar to the porphyry, the main difference being that the former has a much larger percentage of biotite, a smaller percentage of quartz, and more plagioclase. The fact of its distribution, the lack of sharp contacts, the mineralogical similarity of composition, but dissimilarity of the proportions of constituent minerals, lead to the belief that it is a differentiation from the same magma that supplied the granite porphyry.

This is somewhat the reverse of the usual differentiation of acidic magmas, but enough evidence of such a process has been offered by competent investigators to make it a plausible theory.¹

**Granite Porphyry.** This is the largest intrusive at Silverbell. It occupies the Central area, almost surrounding the main limestone outcrop.

On the surface it weathers to a yellowish brown color. In cuts of shallow depth it has a mottled pinkish and white color, characteristic of many of the badly altered siliceous porphyries of the copper districts of the Southwest. Underground in places it has a much fresher appearance, being a light gray.

It is very intimately fractured, so much so that it was impossible to trim a museum specimen from it.

It consists essentially of quartz, orthoclase and biotite in a granophyric ground mass. The quartz occurs as medium, even-sized grains which is a splendid aid in identification in the hand specimen. The orthoclase has been altered in most cases to a mass of sericite and kaolin. Biotite is much less abundantly developed than in the granite. Almost no biotite can be seen in specimens from the surface, but underground it is found to contain biotite consistently.

A large part of the ground mass in some of the slides examined was composed of secondary quartz. Silicification is apparent even in the hand specimen. The feldspars have been attacked and some of the quartz phenocrysts preserve the shape of the feldspar. Veinlets of silica also traverse the rock.

This rock has, hitherto, been called Alaskite porphyry. The same objection to this title as for that of the Mt. Hope
granite holds here, though perhaps not to the same extent. But since underground the porphyry carries biotite, and since silicification and ordinary surface weathering must have removed much of this mineral, the name granite-porphyry is the better of the two.

**Pyroxene Porphyrite.** Cutting both the Mt. Hope granite and the granite porphyry are many small dark, basic-appearing dikes.

On the surface they weather to a bluish gray mass, and are more subject to disintegration than the enclosing rock.

Underground they are of a deep black color, with a highly splendent ferro-magnesian mineral, which in the hand specimen appears to be biotite.

Under the microscope they are seen to be composed very largely of common pyroxene phenocrysts in a ground mass of plagioclase, which varies in composition from medium to basic labradorite. Biotite is present in some slides, entirely absent in others. The percentage of feldspar present is not constant. One dike was made up almost entirely of pyroxene, so much so as not to make the name pyroxenite a misnomer. The rule, however, is that ground mass is composed essentially of feldspar microlites. Large flakes of magnetite speckle all the slides.

The pyroxene has in many instances been wholly altered to chlorite. The feldspars are much fresher than those of the larger intrusives, that is in specimens taken in the mine.
They have not been subjected to an alteration that produces sericite. Only surface weathering has been active in decomposing them.

The texture of these dikes is somewhat lamprophyric, but not strikingly so. Their composition is that of a diabase, but without diabasic structure. Considering that the texture is neither diabasic nor distinctly lamprophyric, the name pyroxene porphyrite has been assigned them.

**Granite Porphyry.** One large dike 6 feet in width was encountered on the 200 level and picked up again on the 300. It does not outcrop at the surface.

It is a gray rock with large white phenocrysts of orthoclase and some plagioclase. A few phenocrysts of quartz together with some biotite are present. Most of the biotite is of a grass green color in thin section. The ground mass is composed of quartz and orthoclase, quartz being the major constituent. Pyrite is disseminated throughout the dike.

**Syenite Porphyry.** West of the Kurtz shaft, several hundred feet from the granite limestone contact were found two small, almost circular outcrops of a fine grained greenish-gray rock.

Any accurate determination megascopically is impossible. The microscope shows that this rock is composed of orthoclase and a very badly chloritized ferro-magnesian mineral, with the characteristic needle-like shape of hornblende. The alteration of this mineral is so complete that the extinction angle cannot
be accurately measured. However, in places the extinction seemed to be parallel to the direction of elongation. This would suggest biotite. One section showed a phenocryst with the crystal outline of hornblende. This suggests then that the hornblende has been altered to biotite.

These areas are undoubtedly differentiates from the granite magma. Their composition and occurrence is that of a minette, but their texture is too unlike that of minette to permit the use of that term. They are designated here as syenite porphyries.

Age Relations of Intrusives. The order of intrusion has been as follows: Mt. Hope granite, granite porphyry, biotite granite, and pyroxene porphyrite. The fact that the granite porphyry dips under the Mt. Hope granite is the reason for assigning such a relation between the two. The biotite granite is, of course, considering the relation to the granite porphyry given it in this paper, slightly later than the granite porphyry, but following very closely. The pyroxene porphyrite dikes are definitely later than any of the above named. They were intruded sufficiently long after the general period of mineralization to escape the alteration consequent to that event.

The granite porphyry dike described from the 200 and 300 levels cannot have been very much later than the intrusion of the larger porphyry, for it exhibits the sericitic alteration of the enclosing rock.

As to absolute age. Both the Mt. Hope granite and the
granite porphyry are found in intrusive contact with the limestone. The limestone is in part Mississippian. Therefore, it can be stated definitely that the intrusion of the older rock is at least as late as Mississippian, probably post-Carboniferous.

These intrusions then occur in the general period of activity that took place over Southern Arizona in Mesozoic time at Ray, Miami, Bisbee, etc. No younger series occur here as at Bisbee to make it possible to definitely assign an upper and lower limit viz: Post Carboniferous and pre-Cretaceous.¹ The evidence at Silverbell is sufficiently definite, however, to permit its being grouped with the other districts named.

Faulting and Fracturing. Traversing all of the rocks are two prominent systems of fractures, roughly N.-S. and E.-W. There is considerable variation in direction but the average is that given above. The E.-W. set is more pronounced than the N.-S. one.

These are of great economic importance as will be seen later when the ore deposits are discussed.

The most probable explanation of their origin that suggests itself is that the underlying magma of the granite porphyry, which at a considerable depth covered a much larger area than at the surface, cooled and contracted evenly. The two sets of fractures resulted from the attendant strain

¹ Prof. Paper 21. U.S.G.S., p. 84.
Typical Chalcocite Veinlet. (X 140)
Cc. - Chalcocite, Py. - Pyrite,
Ga. - Gangue.

Chalcocite and Covellite Replacing Chalcopyrite. (X 280)
Cpy. - Chalcopyrite, Cc. - Chalcocite, Cov. - Covellite.
placed on the already consolidated surface rocks.

There has been a great deal of minor movement particularly along the joint planes. Gouge-and slickensides are common, but no faults of any magnitude were disclosed. Some of the pyroxene porphyrite dikes have been displaced a few feet. Other than this, faulting seems to be absent from this particular area.

**ECONOMIC GEOLOGY.**

**Mineralogy.**

The following list includes only those minerals found on the El Tiro property. The mineralogy of the whole district would include in addition lead and zinc minerals, and several contact silicates not developed in this particular area.

Native Copper. It has been found in small quantities in a few stopes but always associated with either carbonates or oxides of copper, - it is always a secondary product. Small specks of it were observed in some of the veinlets of chalcolite. Its relation is such that it plainly results from the direct breakdown of chalcolite.

Pyrite FeS₂ This is the most abundant metallic sulfide of the district. It occurs disseminated in the porphyry, to some extent in the altered limestone, also in numerous veinlets in the fractured porphyry. It is not commonly crystallized,
though cubes of pyrite can be found.

**Chalcopryrite** $\text{Fe}_2\text{Cu}_2\text{S}_4$. This mineral, though abundant in the larger contact deposits of the district, is not very abundant at El Tiro. It is found intergrown with pyrite in polished sections. Its association with pyrite shows that in this particular instance it is a hypogene sulfide. It also occurs sparingly in the garnetized limestone of the El Tiro property.

**Bornite** $\text{Cu}_5\text{FeS}_4$. This mineral is very rare. It was noted only under the microscope, where it appears intergrown with chalcopyrite, forming very fine borders around pyrite grains. This type of occurrence is somewhat unusual. Most of the area between the pyrite grains is filled with chalcopyrite. As a rule the replacement of one mineral by another begins at a contact between two other minerals. That is not the case here, however. It is not very probable that the bornite is hypogene. The chalcopyrite associated with it results perhaps from the breakdown of the bornite, a process that might be termed "de-enrichment." An attempt was made to photograph this intergrowth. It was so fine that oil immersion had to be resorted to. The contacts between the different minerals lacked sharpness enough to make the result a success.

**Chalcocite** $\text{Cu}_2\text{S}$. This is the mineral that has made the economic working of this deposit possible. A good part of it is of the type described as "sooty" and is everywhere undoubtedly
supergene. It occurs as a direct replacement of pyrite, particularly in the veinlets of that mineral.

**Covellite CuS.** A very small amount of this sulfide was observed. That it was found at all was accidental. In one polished section it was noted forming beautiful dark blue dendritic shaped replacement in chalcocite.

**Molybdenite MoS₂** Is also rare. It was seen in small areas in fairly fresh porphyry from the 200 level and also noted in the gouge of a small fault on the 300. The presence of some molybdenite in the disseminated copper deposits of the southwest is quite characteristic. In one small prospect in limestone, north of the Kurtz shaft, molybdenite was found in fairly large amounts.

**Cuprite Cu₂O** Of the oxidized minerals this is by far the most important. It is associated with the chalcocite and forms a considerable portion of the workable ore. The numerous basic dikes described above are very permeable and oxidation has gone further in them than in the wall rock. As a consequence they run quite high (up to 10%) in "red oxide" ore. A large part of the cuprite is of the variety known as chalcotrichite. This brilliant scarlet mineral with a dark basic dike for a background, makes a striking beautiful sight. Cuprite also occurs crystalline in small cracks and vugs. The crystal forms are simple, the cube predominating, though the dodecahedron is also developed occasionally.
Manganese oxide $\text{MnO}_2$. Occurs as fine black grains in the decomposed breccia on the 300 level. No material was good enough to even permit a guess as to the particular mineral.

Limonite. $2\text{Fe}_2\text{O}_3\cdot3\text{H}_2\text{O}$. Occurs widely as a stain. Its greatest concentration is on the uppermost levels, whereas other heavy gossan has been developed.

Azurite $2\text{CuCO}_3\cdot\text{CuO}\cdot\text{H}_2\text{O}$. This basic carbonate of copper is very sparingly developed here. As a stain it is common, but as an ore mineral it is of no consequence.

Malachite $\text{CuCO}_3\cdot\text{CuO}\cdot\text{H}_2\text{O}$. This mineral is of some importance as an ore. It is seen most abundantly on the 200 level where it occurs as beautiful green impregnations in a very badly decomposed and brecciated porphyry. It also occurs in botryoidal form, its color then being a dark green.

Calcite $\text{CaCO}_3$. Is present in nearly every rock, as a result of the breakdown of feldspars in the igneous rocks, and to recrystallization in the limestones. No good crystalline material was found. Large cleavage faces are fairly common.

Chrysocolla $\text{CuSi}_2\text{O}_5\cdot2\text{H}_2\text{O}$. Chrysocolla is present nearly everywhere throughout the mine. It ranges in color from blue green to a beautiful emerald green. The latter type is somewhat unusual. Its clear, even color, and transparency, leads one to believe that it is probably a mixture of chrysocolla and chalcedony. Unfortunately the limits imposed on this work are such that an accurate analysis is not available.
A good specimen of this mineral was obtained from the dump. None was noted underground. It was associated with azurite and apparently is very rare.

Gypsum \(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}\). In the main drift leading into the 200 station of the Kurtz shaft, the walls and roof are coated for many feet with gypsum. This crust is usually about one eighth of an inch in thickness. It is pure white in color, but in places the outer surface is tinged a delicate green due to ferrous iron.

Pisanite \((\text{FeCu}) \text{SO}_4 \cdot 7\text{H}_2\text{O}\). This double salt of iron and copper is present in small amounts, associated always with chalcanthite. It is also found associated with gypsum, on which it has crystallized.

Chalcanthite \(\text{CuSO}_4 \cdot 5\text{H}_2\text{O}\). The walls and roof of most of the old workings of the mine are covered with various sulfates, of which chalcanthite is the most common. On the timbers of the 200 station of the Kurtz shaft, it has collected in crusts over an inch thick, and is quite pure.

Epsomite (?) \(\text{MgSO}_4 \cdot 7\text{H}_2\text{O}\). Is quite abundant in the brecciated zone of the 300 level. It forms delicate white capillary hairs which protrude from the walls. These hairs are frequently more than an inch in length and are very abundant in spots.

Kaolinite \(\text{H}_4\text{AlSi}_2\text{O}_9\) Is very abundant in most places throughout the workings, particularly in an area on the 100
level southeast of the Pozo Verde shaft, where the rock has altered to a mass of kaolin. Nothing else is discernable in places. With increasing depth, kaolin is not so noticeable, at least not to the naked eye.

**Chlorite.** Hydrous Magnesium, aluminum silicate. Is common as an alteration product in all of the igneous rocks. The ferro-magnesium minerals of the pyroxene porphyrite dikes have been altered more to chlorite than those of the other intrusives. On the 300 level, in the gouge of a small fault, in a very badly brecciated area, several fairly large pieces of the variety clinochlore were found.

**Garnet.** Occurs in the altered limestones. It is usually of a brownish color. Stewart gives the following analysis:

\[
\begin{align*}
\text{SiO}_2 & \quad \ldots \quad 36.85 \\
\text{Al}_2\text{O}_3 & \quad \ldots \quad 9.62 \\
\text{FeO}_3 & \quad \ldots \quad 17.54 \\
\text{FeO} & \quad \ldots \quad 1.62 \\
\text{MgO} & \quad \ldots \quad 1.11 \\
\text{CaO} & \quad \ldots \quad 31.87 \\
\text{MnO} & \quad \ldots \quad 0.51 \\
\text{H}_2\text{O}-110^\circ & \quad \ldots \quad 0.27 \\
\text{Total} & \quad \ldots \quad 99.39
\end{align*}
\]

which he recasts in the following manner:
Andradite ........ 53.4
Grossularite ..... 37.4
Pyrope ............ 4.4
Almandite ........ 3.5
Spessartite ..... 1.2

Considering the analysis the name andradite should be given the mineral, for it is the predominant molecule present.

**Epidote** $\text{H}_2\text{O} \cdot 4\text{CaO} \cdot 3(\text{Al},\text{Fe}_3)_2 \text{O}_3 \cdot 6\text{SiO}_2$. Is quite common in the more highly altered sediments north of the Kurtz shaft. It is not present in large amounts anywhere.

**Wollastonite** $\text{CaSiO}_3$. Is irregularly developed. It occurs in scattered crystals through fairly fresh limestone, while in places it makes up the bulk of the rock. It is of a light brown color and in the hand specimen very much resembles tremolite.

**Specularite** $\text{Fe}_2\text{O}_3$. Is developed in the highly altered limestones north of the Kurtz shaft. While not particularly abundant it is fairly common. Poorly formed crystals over half an inch across were found.

**Quartz** $\text{SiO}_2$. Is one of the major constituents of all the igneous rocks, with the exception of the basic dikes, and the main one of the quartzite. Considerable secondary quartz has been formed from the breakdown of feldspar to sericite and by introduction in solution.
Orthoclase $K_2O \cdot Al_2O_3 \cdot 6SiO_2$. Is by far the commonest feldspar, being the important feldspar of all the acidic intrusives.

Plagioclase. Occurs as a minor constituent of the acidic rocks. It ranges in them from albite to andesine. The variety labradorite is the feldspathic constituent of the pyroxene porphyrite dikes.

Biotite $(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$. Is the commonest ferro-magnesian mineral. Usually it is of the ordinary yellowish brown variety (as seen in thin section), but one occurrence of a grass green variety was noted.

Hornblende. Metasilicate of calcium and magnesium. Is a fairly common constituent of both the granites. It is very subordinate in amount to biotite.

Pyroxene. Metasilicate of calcium and magnesium. Forms the main ferro-magnesian mineral of the pyroxene porphyrite dikes. Interpenetration twins are common in thin section.

Magnetite $Fe_3O_4$. Can be seen only under the microscope. It occurs as grains uniformly scattered over the slide.

Sericite $(H,K)AlSiO_4$. The development of sericite is characteristic of all the rocks of the El Tiro, with the exception of the pyroxene porphyrite.
PLATE II.
PLAN
of the
100, 200 and 300 LEVELS

100 Ft. Level

200 Ft. Level

300 Ft. Level

~LEGEND~
- BROWN - MT. HOPE GRANITE
- BLUE - GRANITE PORPHYRY
- GREEN - LIMESTONE
- YELLOW - BRECCIATED ZONE
- RED - DIKES
The mine has been developed to a depth of 300 feet by several shafts and levels, most of which are still open. Extensive work has been done on the 100, 200, 250, and 300 levels while one shaft, the Kurtz, has been sunk to the 400. Sub-levels on the 125 and 150 were found to be caved.

The drifts have been run roughly along the contact between the granite and granite porphyry, following, in general, a brecciated shear zone in which most of the ore bodies have been found. The walls of the drifts will, almost without exception, give copper assays ranging from one half to three percent, but cannot be considered as ore under present conditions. In places pockets are found where the content reaches from five to twelve percent copper which is rich enough to pay mining, shipping, and smelting costs and leave a profit.

No regular system of development has been carried out as the occurrence of the ore bodies does not seem to warrant it. Prospect drifts are driven in places which appear promising to the superintendent from his knowledge of the property. The method of stoping where ore is encountered depends on the character of the wall rock and size of the deposit. In some places square setting is resorted to, in others open stopes are carried up, with platforms built to support the men at work.
Little timber is used in the mine except for chutes, manways, ladders and square sets. The drifts though run through loose crumbling material which can be removed by hand, stand well. Although some parts of the mine had not been worked for years, few signs of caving were observed.

Drilling is done by hand, the miners working singly or in pairs with single jacks. All ore from the upper levels, is trammed by hand to an ore pocket known as the Pozo Verde in the central part of the mine. Here it drops to the 300 where it is again trammed by hand to the Kurtz shaft, where the loaded cars are hoisted to the surface on single deck cages. Here a small electric locomotive hauls the cars, four at a time, to the railroad where they are emptied into gondolas and returned to the mine.

**TYPES OF DEPOSITS**

There are four types of deposits recognizable within the district:

1. Contact metamorphic.
2. Fissure veins in granite porphyry.
3. Fissure veins carrying lead, silver, zinc.
4. Disseminated copper deposits in granite porphyry and granite.

Of these four, only two are found at El Tiro - contact
metamorphic, and disseminated copper deposits in granite porphyry and granite. The disseminated type is the only one of importance here. The contact deposits considering the whole district have been by far the most important type.

CONTACT DEPOSITS.

All through the limestone area just north and west of the Kurtz shaft there is evidence of mineralization. Many prospect holes have been sunk, but with no promising results.

Some primary pyrite and chalcopyrite are seen and occasionally a little copper pitch. Stains of azurite and malachite are common. No concentration sufficient to form an ore body has taken place.

In various places in the mine, apparently isolated blocks of limestone are found. Some of them have escaped alteration almost entirely; a little silicification and recrystallization represents the full effect of the metamorphism. Other areas have been changed to massive garnet and are mineralized only to a slight extent, lean pyrite being all that is observable.

This is a puzzling situation. Why these isolated blocks should escape severe alteration in some cases and not in others is inexplainable. However, the fact remains that none of them at the El Tiro have been mineralized to the extent of making a profitable ore body.
DISSEMINATED DEPOSITS.

This adjective is not strictly applicable to the El Tiro deposit, for the primary mineralization has been controlled by pre-existing fractures. The nature of this system is such, however, that in reality the deposit is disseminated through a large mass of rock. Some mineralization as fine impregnations has occurred, but the larger percentage of the primary ore minerals were deposited in definite veinlets.

The ore being shipped during the working period of this thesis consisted of two types - completely oxidized, containing cuprite and malachite as the chief minerals, and enriched chalcocite veinlets showing but little oxidation. The richest ore specimens obtained consisted of pyrite, chalcopyrite, chalcocite, and covellite, the minerals being named in the order of their deposition. No ore of such a composition or grade is being mined at present.

Primary Ore. Mineralogically the composition of the primary ore is extremely simple. It consists of pyrite, associated with a small amount of chalcopyrite. No other ore minerals positively of primary origin were noted.

The pyrite occurs in veinlets along the systems of fractures previously described. The formation of an economic
PLATE III.

LONGITUDINAL SECTION LOOKING WEST.

NE-SW CROSS SECTION THRU POZO VERDE LOOKING SOUTHEAST.
deposit is due to the enrichment and oxidation of these veinlets. The oxidation has been controlled by a zone of shearing and brecciation along the contact of the Mt. Hope granite and granite porphyry.

Structural features Determining Position of Ore Bodies. Along a line drawn from the Kurtz to the Williams shaft - roughly northwest by southeast - is a zone of pronounced brecciation.

On the surface it is not as apparent as might be expected, but there is unmistakable evidence of it in several places. In the creek bottom below the Dietz shaft there is a good exposure of finely brecciated granite porphyry. The trend of the zone from there can be noted easily, for a pronounced saddle in the first ridge to the south has been formed by erosion.

A shallow surface tunnel about one quarter of a mile north of the Kurtz shaft gives an excellent exposure of this zone.

This breccia lies mostly within the limits of the granite porphyry. The Mt. Hope granite is also broken up, but neither as intimately nor as far from the contact.

A determination of the original material composing this breccia is in places very difficult, for the whole mass at times has decomposed to a soft flour-like mass that defies identification. So soft is it that on the 300 level the main drift was run for many feet without the aid of dynamite. It is possible, however, to find scattered pieces that have escaped complete decomposition. A determination of these shows that the
mine workings lie mainly within the limits of the granite porphyry.

An explanation of such a phenomenon is, of course, always problematical, but a survey of the observable facts gives rise to an explanation not wholly improbable.

It is not believed that this is a zone of major faulting, for the pyroxene porphyry dikes cutting both granite and granite porphyry are not dislocated by faulting. There is no evidence underground that there has been other than minor faulting.

Such a statement is difficult to demonstrate definitely. There is a possibility that faulting occurred before the injection of these small dikes, and also before the enrichment of the ore body.

It is not conceivable that such an intimately fractured zone could be produced other than by repeated movement, and the probability is that displacement in the aggregate was not large.

The granite porphyry dike, described on the 200 and 300 levels may give a clue. It is essentially of the same composition as the granite porphyry and was injected before the stage of mineralization was complete, for it carries finely disseminated pyrite and has been subjected to the same alteration as the enclosing rock. This dike, then, indicates a renewal of movement of the magma beneath. This rise and consequent settling against a rigid mass of granite could easily have produced such a zone.

Later minor adjustment along fracture planes has aided in
the completion of the process.

That this zone is the controlling structural feature of enrichment and oxidation is definitely demonstrable. Laterally the passage from oxidized to primary zone can be made. On any of the levels, in crosscuts run out of the brecciated zone into either granite or granite porphyry, all that is encountered is barren pyrite or veinlets slightly enriched with chalcocite. There is a total lack of any of the oxidized minerals of copper.

Thus the present ore body is due to chalcocite enrichment and subsequent oxidation of a pyritic ore, lying mainly in the granite porphyry.

**Enrichment of the Ore.** The various stages of enrichment and oxidation can be worked out quite definitely in this deposit.

As a rule chalcocite has directly replaced pyrite. Where sufficient chalcopyrite has been present this replacement has taken place at the expense of chalcopyrite rather than pyrite. Some gangue (quartz) has been introduced after the formation of the chalcocite.

As has been mentioned before, bornite has played almost no part in the enrichment processes.

Chalcocite has been oxidized largely to cuprite, and the cuprite then changed to the carbonates by the action of CO$_2$. Nearly always in the oxidized ore, a core of cuprite surrounding malachite and chrysocolla is present. Malachite does occur without the association of cuprite.
According to Graton and Murdoch⁴ chalcocite is oxidized directly to a soluble condition, the sulphate. The result of this action is the formation of "sooty" chalcocite, an incipient stage of decomposition. The "sooty" variety is everywhere found associated with the chalcocite.

Also under conditions of direct oxidation, the sulphur molecule is oxidized, leaving native copper intimately associated with the chalcocite². This action is observable in a few instances. It has not resulted in the formation of other than microscopic specks of native copper.

Some larger amounts of native copper have been formed, but from the breakdown of cuprite and malachite.

The oxidation of pyrite to limonite has left a gossan of variable thickness and distribution overlying the ore deposit.

The depth of oxidation within the brecciated zone is unknown. The deepest workings are on the 300 level. Judging from the nature of the wall rock there, it is practically certain that oxidation extends several hundred feet deeper.

The zone of the oxidized ore minerals does not extend to the depth of general oxidation, for little ore has as yet been found on the 300 level. The ore body has a southeasterly

---

² Ibid. p. 55.
dip as shown in plate III.

The relation of the present water level to oxidation cannot be stated for the permanent water level is just a few feet above the 300 station of the Kurtz shaft.

Chalcocite enrichment has extended in depth to the 250 foot level at least. On this level the chalcocite occurs only as thin films on pyrite and is too lean to form ore. All of the workings on the 250 are out of the badly brecciated zone, so this depth is more representative of the normal depth of enrichment without any structural feature aiding the process. The probability is that the chalcocite zone does not extend to a much greater depth.

ORIGIN OF THE ORE.

There are only two possibilities for the ultimate source of the ore - the granite porphyry and the Mt. Hope granite. Without any doubt the former is responsible. The Mt. Hope granite occurs only on the western boundary of the district. The granite porphyry almost completely surrounds the large limestone mass in which the most valuable ores have been found. Furthermore practically all of the El Tiro deposit occurs within the porphyry. The Mt. Hope granite may have been slightly mineralized, but the greater probability is that its mineralization is due to the granite porphyry.

Extensive churn drilling has been done in the Mt. Hope
granite south and west of the El Tiro property. The presence of a low grade ore body has been reported but the records of these drillings were not available for this report. It is doubtful whether or not they would throw any light on this particular problem. The drilling was done not far from the granite porphyry contact, and the ore reported may be in the porphyry. The passing from one rock to another, both of such similar composition, might easily escape detection. Should this reported ore body be within the granite, it would not invalidate the statement made above, for the distance from the porphyry cannot be great.

**Types of Alteration and Nature of Ore-Bearing Solutions.**

Two general types of alteration are represented. Contact metamorphic in limestone and hydrothermal.

The effect of the first has been to recrystallize the limestone into marble, develop garnet, wollastonite, epidote, specularite and to deposit pyrite, chalcopyrite, and molybdenite. More or less silicification has been attendant upon both types.

As would be expected in an area where the various rocks are of such similar composition, there has been no pronounced contact action between them.

The second type has developed sericite from the feldspars, chloritized the ferro-magnesian minerals and introduced silica. Silicification evidently continued longer than sericitization for quartz gangue has been introduced into the ore after the formation of some chalcocite.
These two distinct types have been produced by the same solutions. Their action on the igneous rock was essentially that of destruction of the primary silicates; on the limestone that of addition of constituents not normal to the rock.

The minerals listed above are generally considered to be formed at high temperatures, although pyrite and chalcopyrite occur other than as high temperature minerals. Recrystallization of limestones can be effected also by other than contact metamorphic processes. According to Lindgren the temperature of contact metamorphic action ranges from $300^\circ - 800^\circ$.

It is evident then that the solutions introduced Fe, Cu, Mo, S., SiO$_2$. F. The alumina which forms a constituent part of the garnet and epidote could easily have been included in the limestone itself, probably as shaly layers. There is no regular development of epidote, however, that would corroborate such a statement.

Apparently there has been no development of contact silicates in the granite or granite porphyry. That such a replacement has taken place in the intrusive near the contact with sedimentaries has been established in a few cases, but generally such action is slight.

North of the Kurtz shaft about one-half mile there are several prospect pits dug at the contact of massive garnet rock

---

1. Fluorite is common on the dump of the Mammoth Mine, though not observed at El Tiro.
and granite porphyry. These contacts are sharp, and the porphyry while showing its usual alteration to kaolin and sericite, has none of the contact silicates present in the adjoining rock.

Stewart mentions such a replacement at an "Alaskite" (granite) limestone contact further to the east. The El Tiro seems to offer no such occurrence.